High Luminosity LHC

BEAM INSTRUMENTATION AND DIAGNOSTICS FOR HIGH LUMINOSITY LHC

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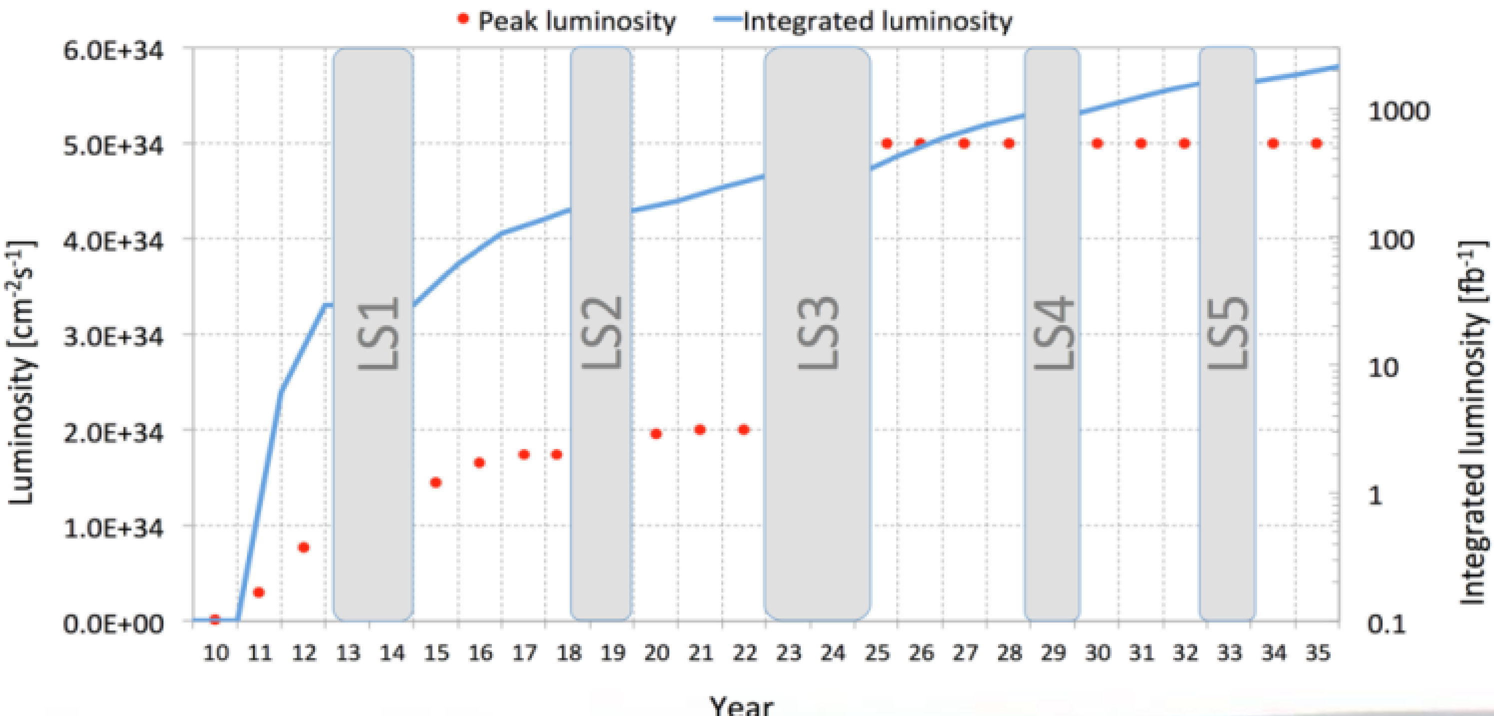
(Beam Gas Curtain project review – October 2016)

Outline

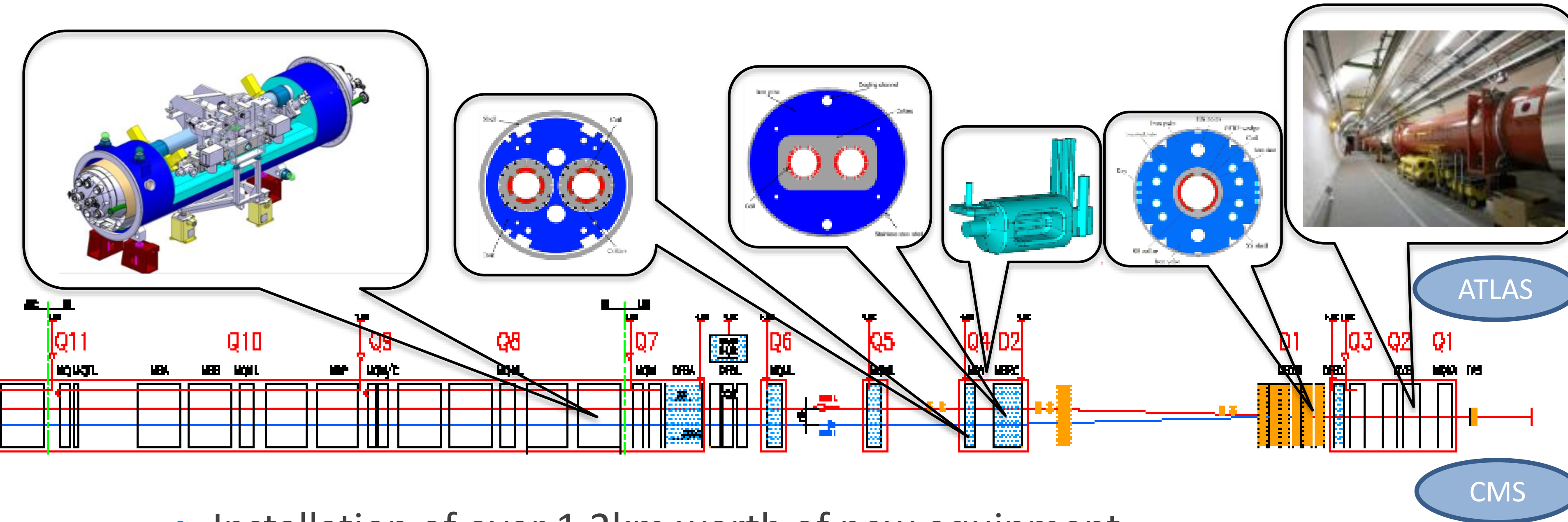
- Goal of the High Luminosity LHC Project
  - Main upgrades required
- Beam Instrumentation Challenges (WP13)
  - Beam loss monitoring
  - Beam position monitoring
  - Beam size measurement
  - Intra-bunch diagnostics
  - Halo diagnostics
  - **Diagnostics to characterise electron beam devices**
    - Hollow e-lens & long range beam-beam compensator
- Summary

Goal of High Luminosity LHC

- Prepare LHC for operation beyond 2025
- Achieve a total integrated luminosity of 3000 fb^{-1} by 2035
  - Integrated luminosity of 250 fb^{-1} per year
  - Levelled luminosity of 5×10^{34} cm^{-2} s^{-1}
- Ten times luminosity reach of first 10 years of LHC operation



Critical zones around ATLAS & CMS



- Installation of over 1.2km worth of new equipment
  - New triplets using Nb_3Sn technology
  - Addition of Crab Cavities & new D1, D2, Q4 & correctors
  - 11 T Nb_3Sn dipole to allow extra collimator in dispersion suppressor
- Elimination of technical bottlenecks
  - Cryogenic system upgrades
  - Relocation of power converters – high temperature superconducting links
- Need for new beam instrumentation to further optimise the machine

Beam Loss Monitoring for HL-LHC

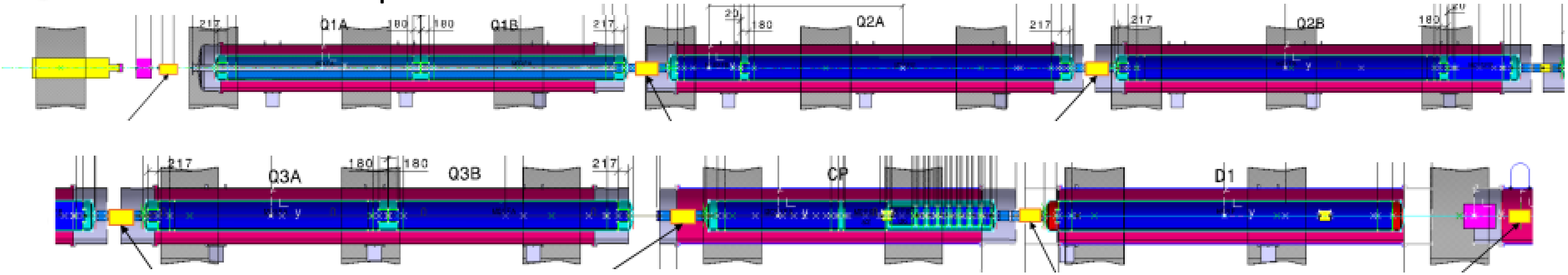
- Essential for safe & reliable operation of LHC
  - Prevents damage to accelerator components
  - Avoids quenches & associated time-consuming cryo recovery

- Existing system
  - Meets needs of the HL-LHC in arc regions
    - ~3000 ionisation chambers
    - Radiation tolerant front-end electronics
- New requirements for high luminosity interaction points
  - Cryogenic beam loss monitors for triplet magnets
  - Radiation Hard front-end electronics

Beam Position Monitoring for HL-LHC

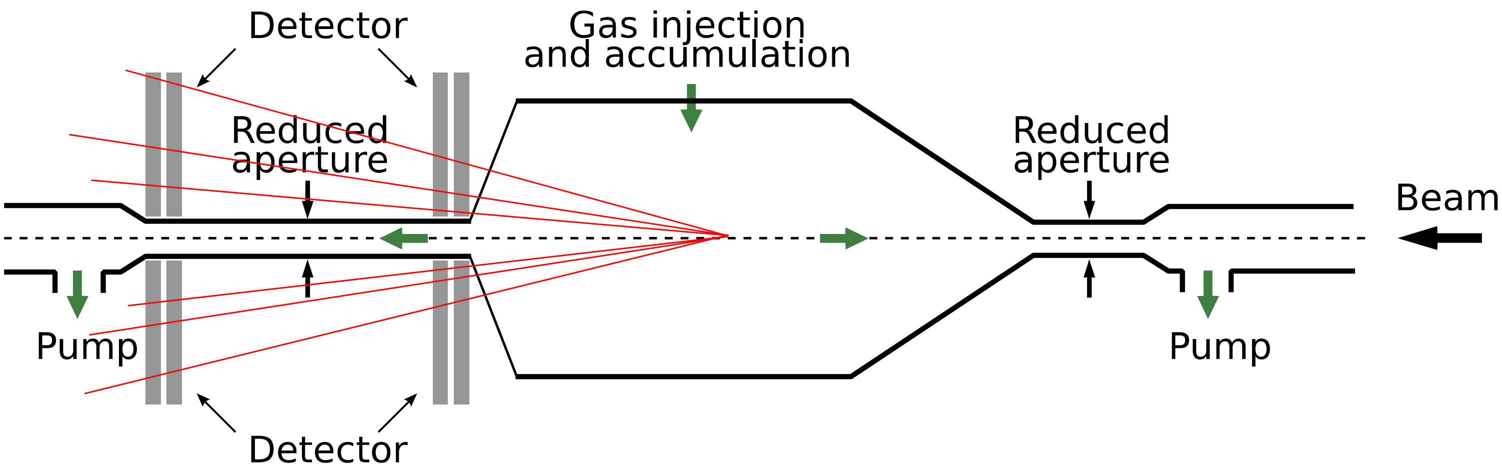
- Beam Position System
  - Over 500 BPMs per beam capable of bunch by bunch acquisition
    - No performance increase required for arc BPMs
    - Renovation of the electronics foreseen for Long Shutdown 3 (2023-2025)
- New BPMs required for HL-LHC insertion regions
    - Directional stripline BPMs
    - Distinguish between both beams (in same vacuum chamber)
    - Limited by signal isolation of one beam on the other
      - Location optimised for time separation
      - Directivity optimised by design

← Towards collision point



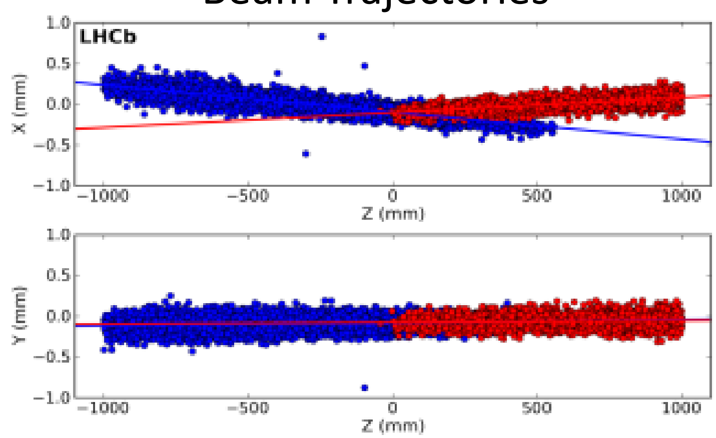
Non-invasive beam size measurement

- The Beam Gas Vertex Detector
  - To overcome limitations of wire scanner & synchrotron light

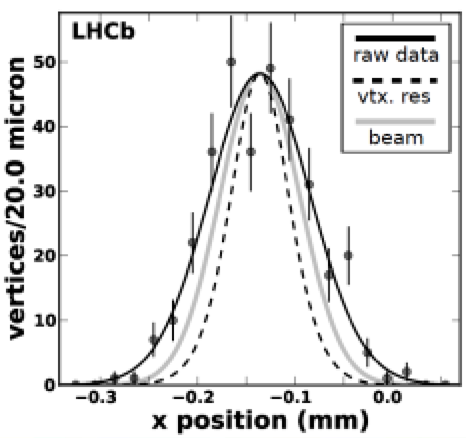


- Concept used by LHCb vertex detector (VELO)
- Collaboration between CERN, EPFL (CH), RWTH (DE)

Beam Trajectories

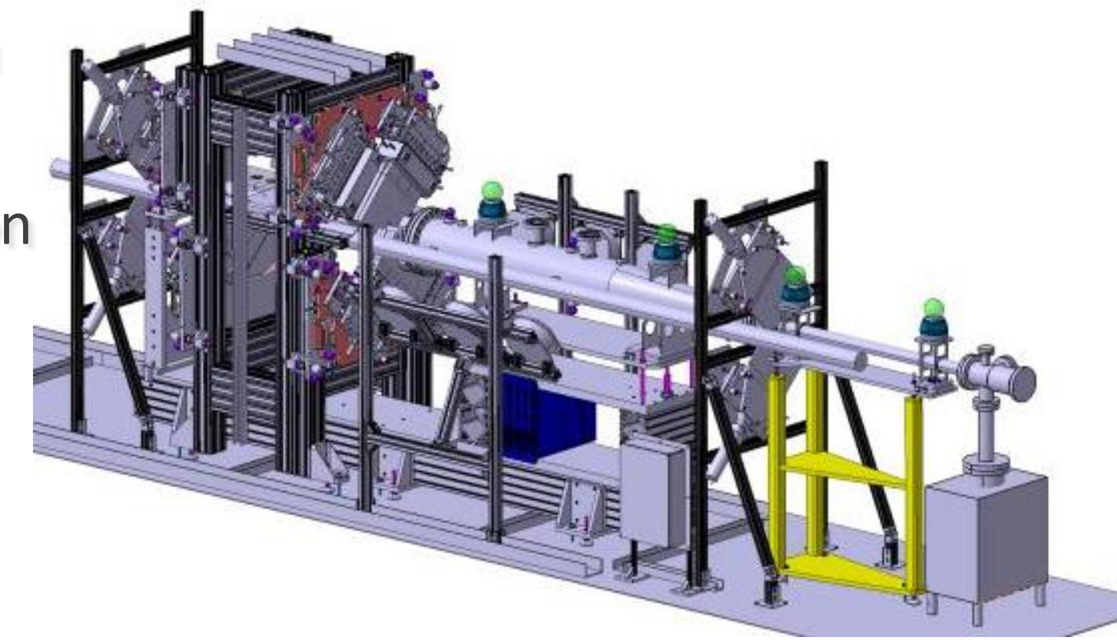


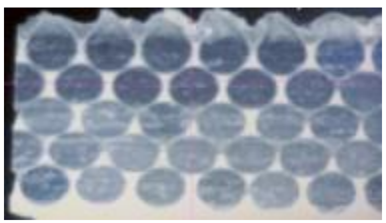
Beam Profile

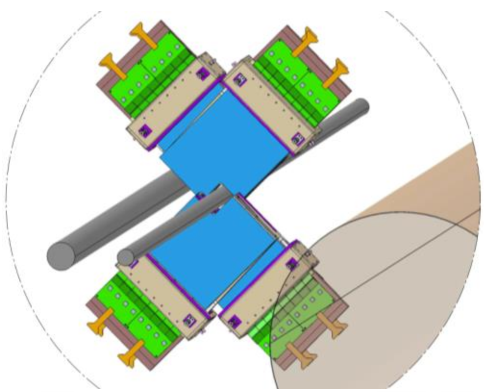


Non-invasive beam size measurement

- Prototype installed on one beam during LS1
  - Detectors based on scintillating fibres
  - Read-out with Silicon Photomultipliers







Quantity	Accuracy	Time interval	Key factors
Relative bunch width	5 %	<1 min	vertex resolution stability
Absolute average beam width	2 %	<1 min	σ_{beam}, σ_{MS}, σ_{extrap} (σ_{hit})

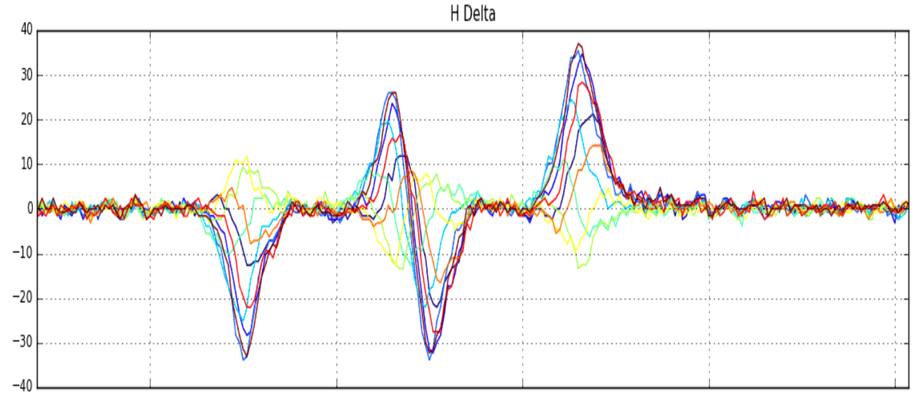
Intra-Bunch Diagnostics

- Already important for understanding instabilities
  - Electron cloud, impedance, beam-beam, ….
- Will also be essential for crab cavity diagnostics
  - Understanding their effect on the beam

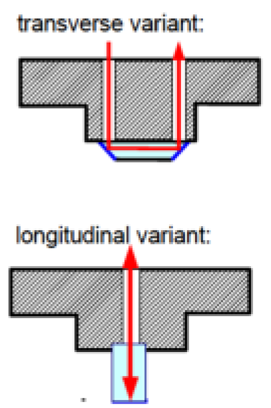
- Two methods being investigated
  - Streak cameras looking at synchrotron radiation
    - Will require new light extraction line to be built
    - Light transport to radiation free area
  - High resolution electromagnetic pick-ups

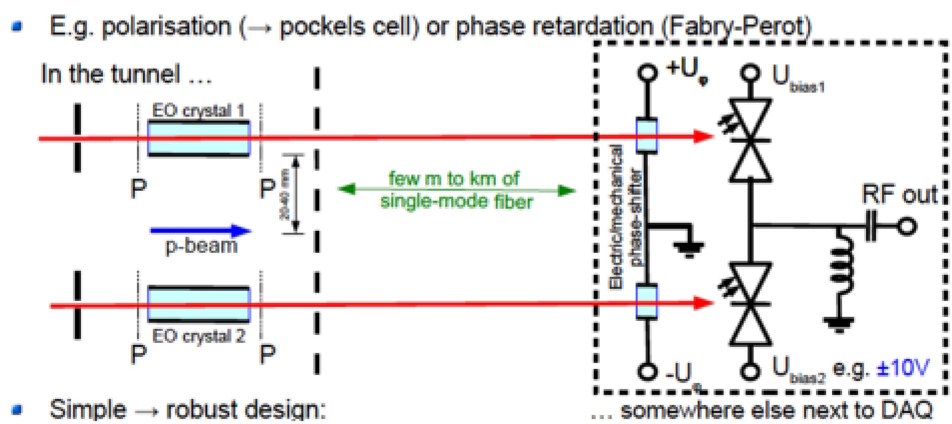
Intra-Bunch Diagnostics

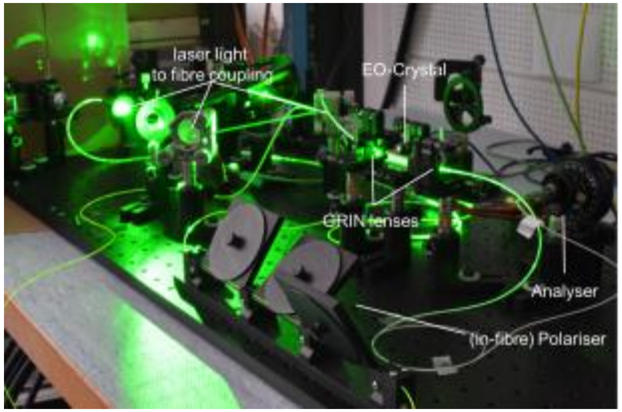
- Electromagnetic monitors already installed in LHC
  - "Head-Tail" monitors provide information on instabilities
    - Bandwidth of some 2 GHz
  - For higher resolution require bandwidth > 10 GHz
    - R&D on pick-ups based on electro-optical crystals



Lithium Niobate	Lithium Tantalate
$LiNbO_3$	$LiTaO_3$







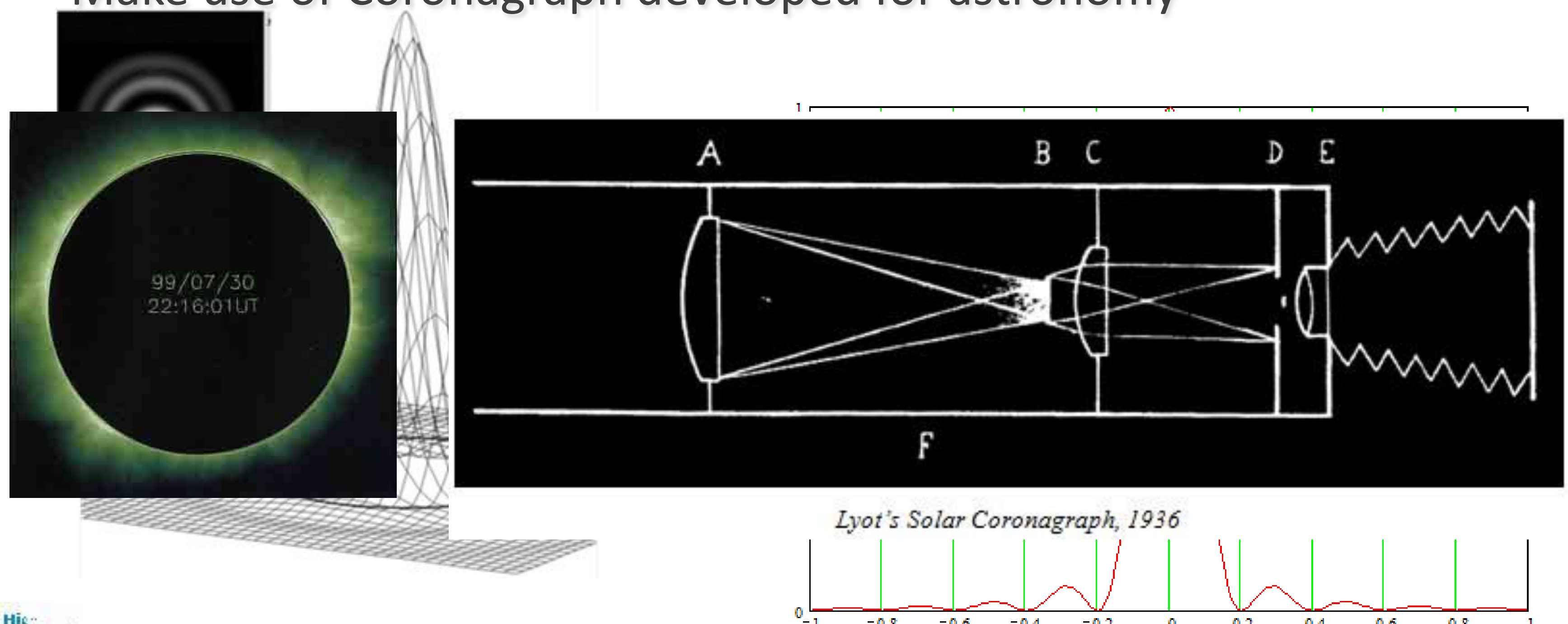
Collaboration with Royal Holloway University of London (UK)

Halo Diagnostics for HL-LHC

- No instrumentation currently installed in LHC to measure the beam halo
  - Needs to be non-invasive to allow use with physics beams
- Important for HL-LHC to understand halo formation
  - Influence of Crab Cavities
  - Long range beam-beam interactions
  - Other core depletion mechanisms that result in lower luminosity
- Important for Machine protection
  - Level of halo will influence operation & protection capability of collimation system
- Important for measuring effectiveness of devices controlling halo formation or acting on the beam halo
  - Long Range Beam-Beam Compensators
  - Hollow electron lenses for halo depletion

Coronagraph for Halo Diagnostics

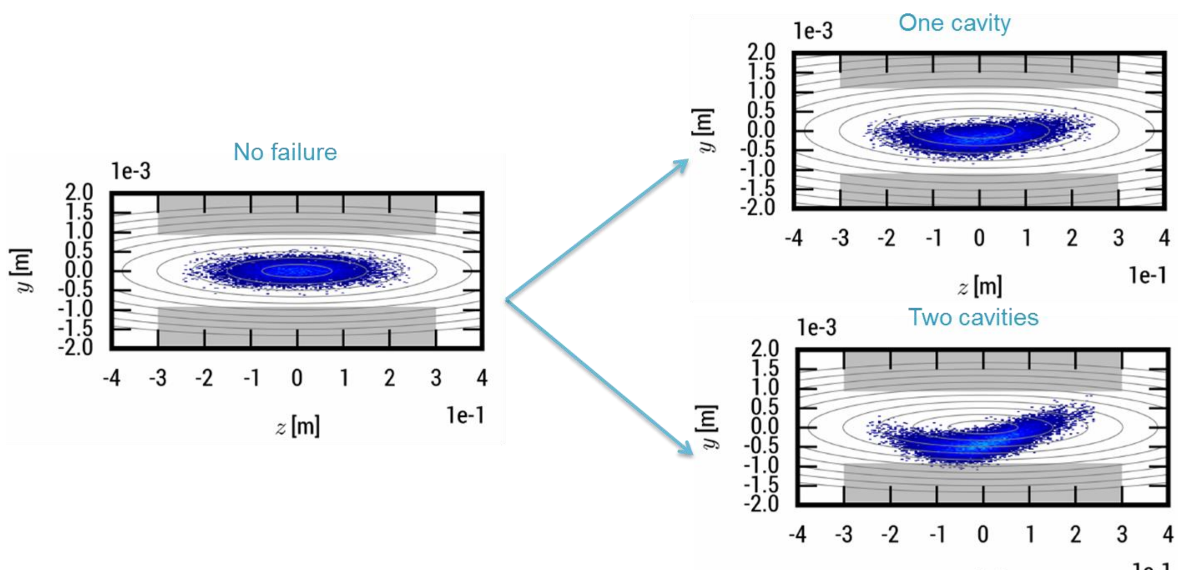
- Diffraction creates fringes surrounding central beam image
- Intensity of fringes in range of 10^{-2} to 10^{-3} of peak intensity
- Masks observation of weak halo at 10^{-5}
    - Need a way to reduce effect of diffraction fringes
- Make use of Coronagraph developed for astronomy



Lyot's Solar Coronagraph, 1936

Active Halo Control for HL-LHC

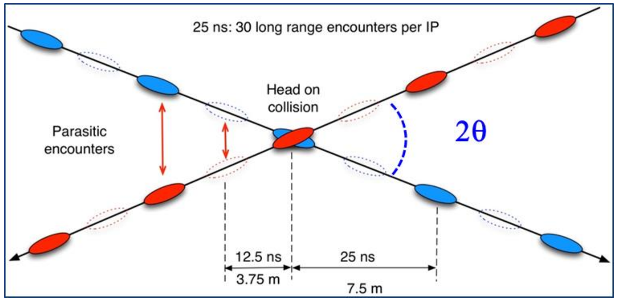
- Review last week recommended that active Halo Control should be implemented
  - The hollow e-lens is the best method for implementing such active halo control
- Mitigation for
  - Crab cavity failures
    - Kick given to beam can damage the collimators if the tails are significantly populated
  - Loss spikes during operation
    - Scaling to HL-LHC from 2012 operation would lead to prohibitive losses
- Hollow e-lens requires non-invasive technique for
  - Aligning e-beam with proton beam
  - Characterising the e-beam on a test stand
- **Why we're here:**
  - **Proposal to use gas sheet in combination with luminescence**



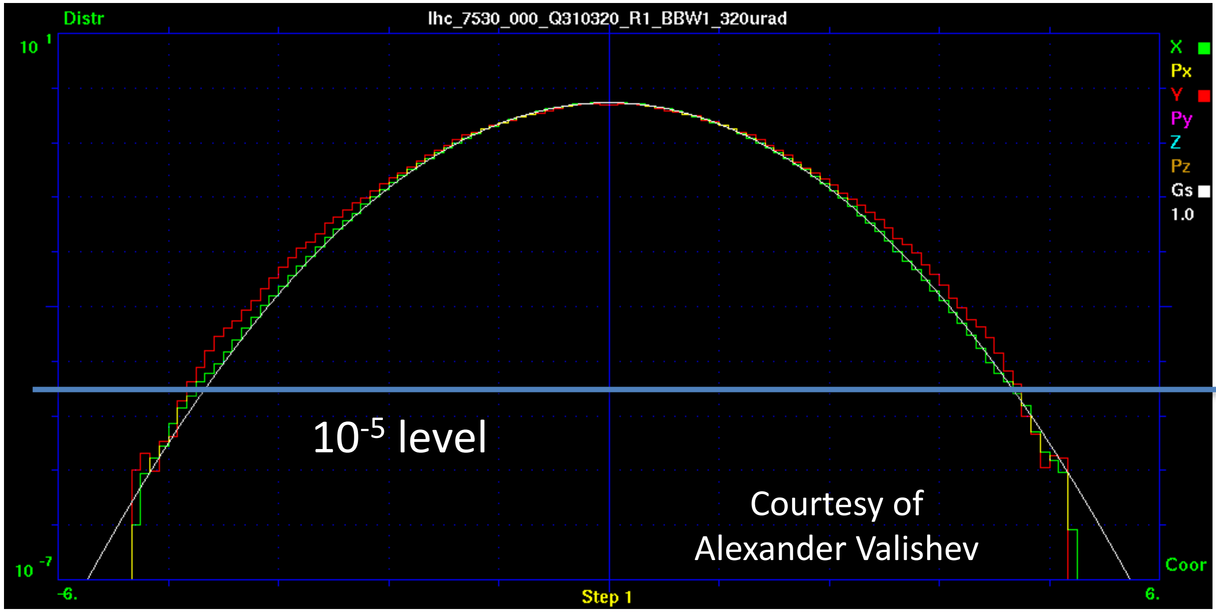
Courtesy A. Santamaria

Long Range Beam-Beam Compensation

- Counter strong effect LHC long-range interactions
  - Use current generating the same integrated transverse force as the opposing beam
  - Corrects all non-linear effects
- Enhances performance reach of HL-LHC
  - Allows smaller crossing angle
- Proof of principle using wire-in-jaw collimators



- Final solution will probably require high current electron lenses
  - R&D ongoing with test stand foreseen
  - Characterisation of e-beam will require non-invasive diagnostics
- Use of gas sheet & luminescence



Summary of Gas Jet Collaboration

- Why?
  - Only viable non-invasive technique identified for the characterisation of high current electron beams in the presence of high intensity and energy proton beams
  - Important for development of electron lens components for hollow e-lens and LRBB compensator
- Objectives
  - Demonstrate production of a high density neutral gas sheet
  - Demonstrate detection using luminescence
  - Produce a system capable of equipping an e-lens test stand
  - Design, produce and test a prototype system that could be installed in the LHC
  - Collaboration partners
    - HL-LHC WP13 and UK collaboration (WP3 - Diagnostics)
      - Agreement in place for 50/50 funding of HL-LHC activities
      - Task 2 : Gas Jet Based Beam Monitor for HL-LHC
        - University of Liverpool & Cockcroft Institute
        - Design, Production and Test of a neutral gas sheet production device
    - GSI collaboration agreement
      - Design, production and test of a luminescence detection system for a neutral gas sheet monitor